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July 25, 1955

Mr. Robert D. Nininger, Assistant Director
Divison of Raw Materials
U. S. Atomic Energy Commission
Washington 25, D. C.

Dear Bob:

Transmitted herewith are three copies of TEI-443, "Zoning of the Bitter Creek vanadium-uranium deposit, Montrose County, Colorado," by Allen V. Heyl, June 1954.

We are asking Mr. Hosted to approve our plan to publish this report as a Survey Bulletin.

Sincerely yours,

George N. Pipiringos
for W. H. Bradley
Chief Geologist

Geology and Mineralogy

This document consists of 27 pages.
Series A

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

ZONING OF THE BITTER CREEK VANADIUM-URANIUM DEPOSIT

MONTROSE COUNTY, COLORADO*

By

Allen V. Heyl

June 1954

Trace Elements Investigations Report 443

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ZONING OF THE BITTER CREEK VANADIUM-URANIUM DEPOSIT MONTROSE COUNTY, COLORADO

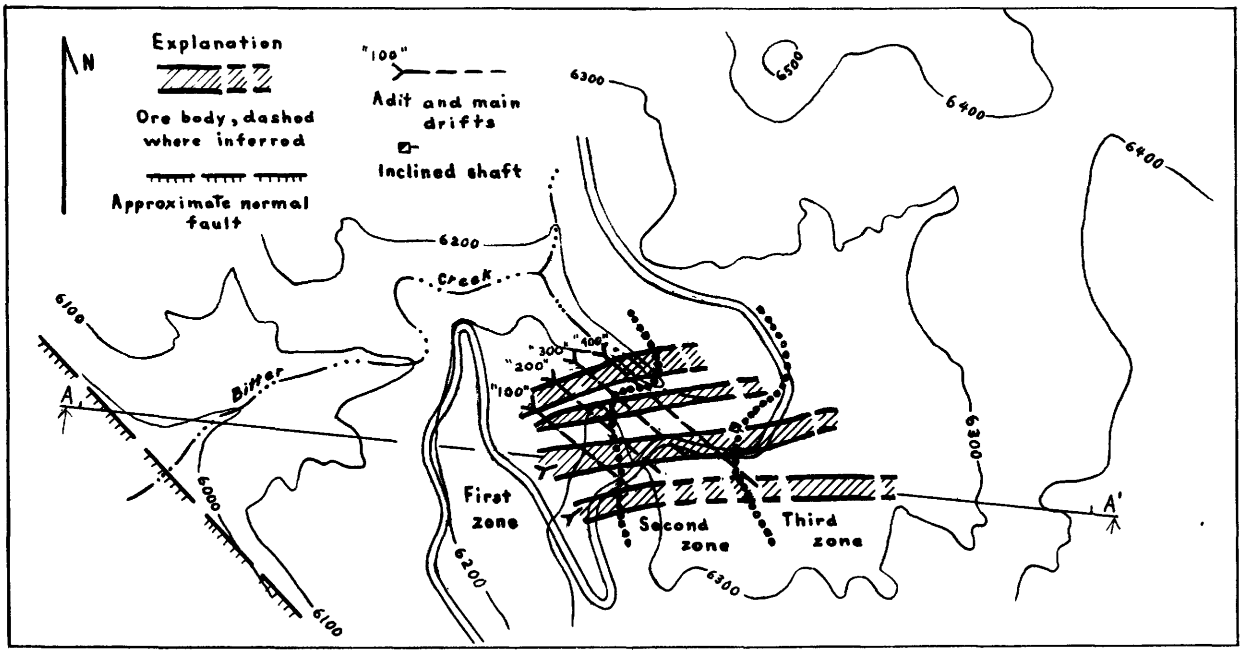
By Allen V. Heyl

ABSTRACT

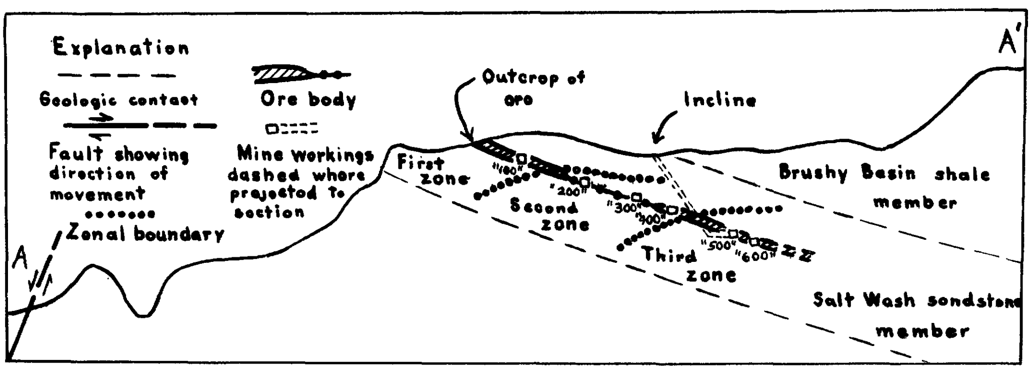
The vanadium and uranium deposit of the Bitter Creek group of mines, south of Uravan, Colo., is in the upper part of the Salt Wash member of the Morrison formation. The deposit shows at least 3 depth zones, as thickness of overlying cover increases, that have distinctive geologic features. The deepest of these zones contains nodular and concretionary masses of vanadium and uranium oxides associated with pyrite and chalcopyrite. These concretionary masses change to the more commonly described disseminated deposits of vanadiferous clays and carnotite nearer the outcrop. Similar, but less marked, zoning is discernable in many other mines in the Uravan district. The depth zones are possibly progressive oxidation products of older primary(?) concretionary vanadium-uranium oxide deposits that contained iron and copper sulfides.

INTRODUCTION

The Bitter Creek group of mines (fig. 1) is in the eastern part of the carnotite-producing "Uravan mineral belt" (Fischer and Hilpert, 1952, pl. 1), Mesa, Montrose, and San Miguel Counties, Colo. and the adjacent parts of Utah. They are about 6 miles south of Uravan, Colo. in the SW 1/4, SW 1/4 sec. 1, T. 46N., R. 17 W., Montrose County,



Plan View



Section (vertical exaggeration about 3 times) (Looking N)

Figure 1. -- Diagrammatic plan and section of the Bitter Creek mine and its ore bodies showing zones

Colo. (Fischer, 1944). The mines are reached by unpaved road via Long Park from Uravan or from Colorado route 90 in Paradox Valley. They are owned by the Vanadium Corporation of America and were leased to Mr. Vard Beckman in 1952.

The Bitter Creek vanadium-uranium deposit is one small group of ore bodies of the many in the Morrison formation in western Colorado, eastern Utah (Fischer, 1944), and northern Arizona. Concretionary masses of vanadium and uranium oxides are in the deepest parts of the mine. The concretionary masses gradually change to the more commonly described deposits (Fischer, 1942, Weir, 1952) of vanadiferous clays and carnotite near the outcrop. Less marked but similar changes are discernible in many of the other mines, particularly those beneath thick covers of rock in the Uravan district of the "Uravan mineral belt".

FIELD WORK AND ACKNOWLEDGMENTS

This paper is the result of studies made in the summer of 1952 as a part of a program of detailed geologic mapping by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission. R. L. Boardman, W. D. Carter, M. D. Okerlund and other geologists of the U. S. Geological Survey assisted in the study.

Acknowledgments are made to the Vanadium Corporation of America, owner, and Mr. Vard Beckman lessee, for permitting access to their property and providing maps of the Bitter Creek mine. Acknowledgments are also made to the U. S. Vanadium Co. for similar assistances for properties visited that are owned by them.

GENERAL GEOLOGY

The Bitter Creek deposit of vanadium-bearing sandstone is in the Upper Jurassic Morrison formation (Fischer, 1942, p. 368). The deposit is in the lower part of the upper sandstone beds of the Salt Wash sandstone member (fig. 1, section). These upper beds are commonly light brown to buff (but white to gray where unoxidized), medium-to coarse-grained, massive to lenticular and irregular bedded, and cross-bedded. The Salt Wash member forms an erosion-resistant cliff and bench about 60 feet high. Lenses and thin beds of red shale within the member, as well as red shale pebbles deposited in it, are all altered to pale green in and near the ore body (Weir, 1952). Locally, fragments of fossil plants and trees are abundant; saurian bones are rare.

The rocks of the area are moderately folded into several large northwest-trending folds. The Bitter Creek deposit is in the northeast flank of the collapsed Paradox anticline, which trends N. 50° W. for at least 35 miles. Steeply dipping normal faults along both flanks of the anticline (Fischer, 1944) displace the axial part of the anticline downward, and the competent sandstone beds are cut by many vertical joints that strike northwest parallel to the faults and the anticlinal axis. The beds near the mine strike N. 30°-50° W. and dip 10-25° NE (fig. 1.).

Vanadium-uranium ore from the Uravan district contains from about 1 to 5 percent V_2O_5; most of it contains less than 1 percent U_3O_8. The ore from the Bitter Creek mine has a relatively high ratio of vanadium to uranium as compared with many of the other deposits in the Uravan mineral belt.

GENERAL FEATURES OF THE BITTER CREEK MINE

The Bitter Creek mine (fig. 1) is on the northeast rim of Paradox Valley and is near the center of a semicircular bench about half a mile in radius encircled by hills on the east and north sides. The bench is about 800 feet above the valley floor, and its surface marks approximately the top of the Salt Wash sandstone member of the Morrison formation. A southwest-facing cliff that is formed by the resistant Salt Wash sandstone member marks the edge of the bench towards Paradox Valley.

A small canyon, the valley of Bitter Creek, cuts westward into the bench just north of the mine and exposes outcrops of ore down the dip of the strata to the northeast for about 900 feet. Similar outcrops of ore are exposed southeastward from the canyon near the top of the cliff for about 1,000 feet along the strike of the Salt Wash sandstone strata.

The Bitter Creek deposit is opened along the northwest-trending outcrop by adits, shallow trenches, pits, and open cuts. Four adits and drifts extending from them called the "100, 200, 300" and "400 levels", provide underground access to the mine from Bitter Creek Valley to the north (fig. 1). The "levels" are spaced about 300 feet apart down the northeasterly dip of the beds. The drifts trend southeastward and are within the ore-bearing beds along the strike direction. Each drift cuts the several parallel tabular ore bodies at vertical intervals of from 15 to 30 feet. Stopes along the ore bodies connect the several haulage drifts to form a rhombic pattern. To the northeast of the drifts a steeply inclined shaft provided access to the deeper "500" and "600 levels",

which are also connected to the upper workings by stopes. The difference in altitude from the ore outcrop to the deepest workings is about 180 feet. The thickest cover of rocks above the deepest workings is also about 180 feet.

The ore deposit is large and consists of several parallel tabular ore bodies that extend from the outcrop eastward, and generally down the dip of the beds, for more than 1,000 feet. The ore bodies are essentially parallel to the sandstone beds and at the same horizon, but the individual parts of the ore bodies may cut abruptly across the beds for several feet. The bodies have irregular outlines and range from 10 feet to 100 feet in width and from a few inches to 15 feet in thickness (Fischer, 1942, p. 383). Within the ore bodies the mineralized parts are very irregular, and masses of unmineralized sandstone of all sizes are abundant within the bodies.

Fossil tree trunks, branches, weeds, and leaves are common in the ore-bearing sandstone. The vanadium and uranium minerals show a marked affinity for plant, tree, and bone fragments where they have not been silicified previous to ore deposition. But this plant and animal material is mineralized only within the vanadium and uranium-bearing ore bodies, except in rare examples. Why so in ore bodies but not outside of ore bodies?

Very few faults are exposed in the Bitter Creek mine, even though the outcrop of the ore deposit is only about 1,000 feet northeast of the nearest of the Paradox anticline collapse faults. The observed faults are post-ore reverse faults whose displacements are measurable in inches (fig. 1) and a few small bedding-plane faults along shaly bands. In places, bands of ore follow or end abruptly against these faults along

bedding planes. Well-defined joints, apparently related to the regional structures are abundant, but the joints have not visibly controlled the ore deposition.

ZONING

Three zones in the vanadium deposits are exposed in the Bitter Creek mine as the depth of overlying cover increases (fig. 1): (a) zone 1 consists of vanadiferous-clay deposits,"stained" by a little "carnotite", in lean dissemination, bands along bedding-planes, and curved surfaces called "rolls" (Fischer, 1942, p. 383) (fig. 2a.); (b) zone 2 has blue-black vanadium ores and probably uranium oxides in richer bands, rolls, and disseminations (fig. 2b); and (c) rich nodules and concretions, bands and incipient irregular rolls of black vanadium-uranium oxides, and iron and copper sulfides, compose the third and deepest zone exposed in the mine (figs. 2c, 3). The change between zones 1 and 2 is completely gradational, but the change between zones 2 and 3 appears to be more abrupt.

2a. Vanadium-clay socket roll in the "100" level of the Bitter Creek mine. The roll is located at the junction of 2 shaly layers separating sandstone lenses. This ore contains about 4 to 5 percent V_2O_5 and forms dark gray rhythmic diffusion bands that curve between the 2 shaly layers. The ore is widely diffused between the 2 bands and locally stained by carnotite. Dashed line is a band of limonite.

2b. Vanadium-oxide roll typical of the "300-400" levels of the Bitter Creek mine. The ore is now primarily black vanadium oxides (corvusite, montroseite) and uranium oxide and is richer than the gray vanadium-clay ores. Only a little ore is disseminated between the bands.

2c. Detailed drawing of nodular and banded vanadium oxide ores on incline between "500" and "600" levels of Bitter Creek mine. Ore in nodules ranges between 10 to 20 percent V_2O_5. Note the structural similarities to the rolls shown above and the probable incipient stage of diffusion of the larger ore nodule. (Compare this large nodule with the smaller one and the nodules of figure 3). The bands along the shale layers consist of lean vanadium oxide ore and some brown iron oxides that appear to be alterations and redepositions from the nodules.

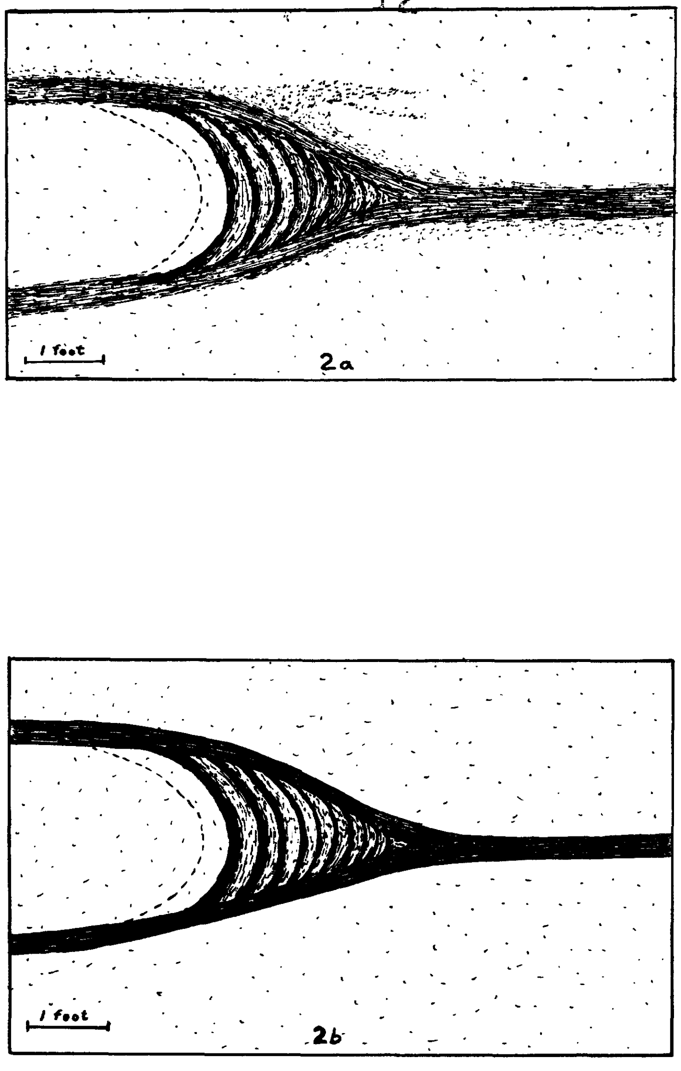


Figure 2. -- Changes with increasing depth in the vanadium-uranium ores at the Bitter Creek mine.

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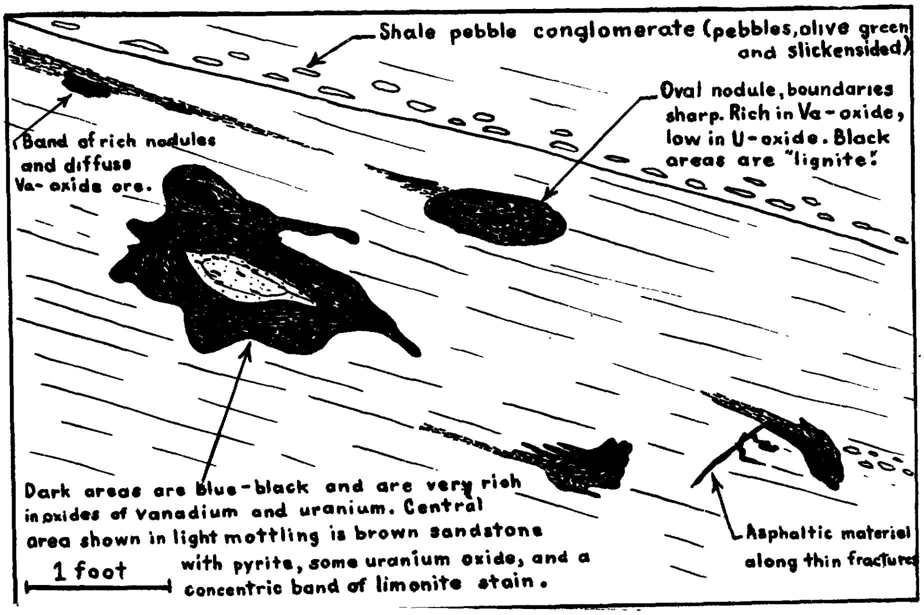

Figure 3.--Ore nodules, "600" Level, Bitter Creek mine. Detailed scale drawing of vanadium-uranium oxide nodules in light brown sandstone. Original pyrite is altered to limonite except in nodules. Note the lignite in some nodules and the asphaltic veinlets. Note also the band of ore shown in the upper left hand corner which contains small rich nodules and more diffuse black vanadium and uranium oxides.

First zone

The near-surface zone or zone 1 (figs. 1; 2a) consists of dark gray vanadiferous-clays, yellow "carnotite", and possibly small quantities of a black uranium mineral deposited in lean disseminations, bands, and well-formed rolls. The ore probably averages between 1 and 5 percent V_2O_5 and less than 0.2 percent U_3O_8 (Fischer, 1942, p. 366-367). These ores are the only ones observed at the outcrops and in the shallow open pits along the strike, and the outcrops down the dip of the beds along the Bitter Creek valley at the north edge of the deposit (fig. 1). They are typical of the near-surface stopes to where the depth of cover over the ore is less than 80 feet.

The only abundant vanadium mineral in the first zone is a gray vanadium hydromica, one of the clay minerals, that has not been fully identified. It forms aggregates of minute flakes that coat the sand grains or completely fill the interstices of the sandstone. Some rauvite ($CaO.2UO_3 .5V_2O_5.16 H_2O$) is found in the upper levels of the mine. 1/

1/ Weeks, A. D., U. S. Geological Survey, oral communication, March 1953.

The principal uranium minerals are probably yellow "carnotite" minerals, carnotite $[K_2(UO_2)_2(VO_4)_2.3H_2O]$, tyuyamunite $[Ca(UO_2)(VO_4)_2.5\text{-}8\frac{1}{2}H_2O$, and metatyuyamunite $[Ca(UO_2)_2(VO_4)_2.3\text{-}5H_2O]$. Much of the yellow color of the minerals is masked by the gray vanadiferous clay. Possibly small quantities of an undetermined black uranium mineral also occur.

The sandstone is stained yellow and brown by limonite. White veins of fibrous gypsum fill a few fractures. Logs, twigs, and woody fragments of dull black lignite are common. A little of this lignite is uranium-rich, but much of it is barren.

The clay ores are in part disseminated rather uniformly through the sandstone, in part concentrated in sheets along the bedding planes, and the rest is in curved rolls. Well-developed rolls are characteristic of the first and second zones of the deposit (figs. 2a and 2b).

Some rolls are localized at the junction points of two shaly bands. In some places these shaly bands appear to be original sedimentary shale layers between sandstone lenses, but in other places the shaly layers may have formed by the dissolving of the quartz grains along bedding planes by the ore solutions.

Second zone

The second zone extends for about 700 feet down the dip from about the "200" level to just above the "500" level. The depth of cover above the zone ranges between 80 and 120 feet. The second zone (fig. 2b) resembles the first but vanadyl vanadates and oxides, rauvite and possibly uranium oxides are the principal ores; the margins of the ore bodies and some rolls are more irregular; the ore is richer and concentrated more in bands rather than

in disseminations. Vanadiferous clay, the principal vanadium mineral of the first zone, is less common, and the yellow carnotite minerals (carnotite, tyuyamunite, metatyuyamunite) were not observed. The principal minerals are greenish-black or blue-black corvusite $\boxed{V_2O_4 \cdot 6V_2O_5 \cdot xH_2O}$, some black montroseite $\boxed{VO(OH), \text{ or } (V,Fe)O(OH)}$, and an undetermined uranium oxide and rauvite 2/. In many of the older stopes orange pascoite

2/ Stern, T. W., U. S. Geological Survey, oral communication, March 1953.

($2CaO.3V_2O_5.11H_2O$)(Weeks and Thompson, 1954), coats the richer ore. The ore-bearing sandstones are limonite stained, and gypsum fills small fractures.

The margins of the tabular bodies and some of the rolls are somewhat more irregular, and the ore minerals are less widely and evenly distributed through the rock, than in the first zone. The ore bands and rolls are black owing to the vanadium oxide minerals and much of the ore is richer in vanadium and possibly uranium. Fewer masses of lean disseminated ore are present between the rolls and ore bands (fig. 2b), and in general, the ore is richer and more spotty. In places, a lean reddish-brown disseminated vanadium ore is seen. It apparently consists of a mixture of vanadium and iron oxides and contains 2 to 3 percent V_2O_5.

A few widely scattered, irregular nodules of rich corvusite-montroseite-uranium oxide ore are found in the second zone closely associated with bands and masses of disseminated vanadium oxides.

Third zone

The deepest zone, exposed in the "500" and "600 levels", contains numerous rich black concretions, nodules, bands, spotty disseminations, a few very irregular rolls of vanadium and uranium oxides, and iron and copper sulfides (figs. 2c and 3). The nodules are very high-grade, ranging between 10 and 30 percent V_2O_5 and 0.1 and 0.75 percent U_3O_8 3/; the quantity

3/ Mr. Beckman, lessee of Bitter Creek mine, oral communications, 1953.

of uranium in individual nodules differs greatly. The nodular masses occur as irregular lumps that have sharp projections, as knobby and amoeboid nodules, and as ellipsoidal concretions, all of which may be from a few inches to 5 feet across (figs. 2c and 3). Many of the bands also consist of rich ore but these bands are lower in grade than the nodules. The disseminations are relatively small and are spotty and local in occurrences. Some disseminations are of lean brown ore that consists of a mixture of vanadium and iron oxides. Where present, the rolls are composed of very rich ore but are imperfectly formed (fig. 2c). Within some rolls irregularly shaped barren masses interrupt the roll surfaces, and diffusion bands in smooth curves are rare.

Montroseite, some corvusite, and black uranium oxides, as yet undetermined, are the principal ores in the third zone. Vanadiferous clays apparently are rare or absent. Pyrite is abundant as small disseminated grains in the black nodules, forms uranium-bearing concretions, and occurs as sparsely disseminated grains in unoxidized parts of the ore-bearing sandstone. Grains of chalcopyrite were also noted in several nodules. Barite was noted, and gypsum is rare or absent. Limonite locally forms diffusion

bands around the nodules and rolls, and it also is intermixed with vanadium oxides in the brown disseminated ores. These brown ores contain hewettite ($Ca\ V_6\ O_{16}\ .9H_2O$) in soft red masses in some places.

Carbonaceous material (fig. 3), consisting of fossil wood and other plant fragments is shiny black and resembles asphalt but appears to be mostly lignite mixed with small quantities of a more liquid substance resembling gilsonite, thucholite, or anthraxolite, is common. In a very few places the more-liquid fraction has flowed into adjacent small cracks (fig. 3). Most of it within the ore is mineralized, but most of it in the barren rock is not vanadium or uranium-bearing. Many of the ore nodules and concretions enclose or are attached to the carbonaceous areas.

The rock is moist in this zone and in the deepest parts of the mine pools of ground water have collected. The third zone appears to be either at the upper limits of the main ground water table, or in the same position in relation to a local perched water table.

Some of the host sandstone is brown and stained with limonite, but the rest is white or gray and contains pyrite grains instead of limonite. Where the sandstone is yellow or brown in color, many of the vanadium-uranium nodules are large and have an irregular shape (fig. 2c). Many such nodules are surrounded by diffusion-bands of limonite, and bands and disseminations of leaner vanadium ore are common near them. The boundaries of the nodules are less sharp and they have a large center of lean ore. In places, irregular rolls are seen but they are not too common. More limonite and less pyrite is present than in the white or gray sandstone.

In the white and gray sandstone the vanadium nodules and concretions are commonly well rounded and have few projections. They are probably composed mostly of montroseite and pyrite. They occur as isolated black ellipsoids in barren sandstone associated with a few adjacent bands or disseminations of ore. The boundaries of the concretions are sharp. Some of them are concentrically banded and closely resemble manganese oxide concretions. The concretionary ore in white or gray sandstone is believed to represent the upper edge of a fourth zone of unoxidized ores.

ZONING ELSEWHERE IN THE URAVAN AREA

Zoning of the vanadium-uranium ores is also found in many others of the deeper buried deposits in the "Uravan mineral belt". Most ore deposits show only the first and second zones, but in some deposits the third zone is present. The black ores of the second and third zones occur in places where the overlying rock cover is sufficiently thick (Weeks and Thompson, 1953, p. 11-12). In some places the change is very gradual over a distance of several miles as in the Long Park group of mines (south of Uravan, Colo.) which trends nearly parallel to the regional strike. The northwestern part of the group contains carnotite and vanadiferous clay ores beneath thin rock cover. The black ores of the second zone begin to occur in small patches (for example, Long Park No. 6 mine) as the cover becomes thicker southeastward. Long Park No. 1 mine about half a mile southeast of the Long Park No. 6, and at greater depth, contains only the black oxide bands, rolls, and disseminations of the second depth zone. The Whitney mine, which is half a mile southeast of the Long Park no. 1, and is beneath the deepest

cover at Long Park, contains nodular ore similar to that of the third zone at Bitter Creek. The Virgin mine, which is a newly opened ore **deposit**, is at a depth of 345 feet, the deepest mine in the Uravan Mineral Belt. Here blankets of black oxide ores occur that contain a black uranium mineral having an X-ray pattern like thorite called coffinite (Stieff and others, 1955), and the ore is even less oxidized than at Bitter Creek 4/. Black ores of the second and third

4/ Weeks, A. D. and Stern, T. W., U. S. Geological Survey, oral communication, May 1954.

zones are found in those ore bodies of Club Mesa (Fischer and Hilpert, 1952, p. 9-10) that lie beneath thick caps of overlying rocks (fig. 4), even though the ore body may lie up-dip from the outcrop. The strata in Club Mesa strike northwest and dip gently eastward. Ore bodies near the rim of the mesa and overlain by a thin cover of rocks (that is, the Club, Mill No. 2 and Saucer Basin mines) consist of vanadiferous clay and carnotite ores, but those beneath the thick cover of capping rock near the central mesa cap of Burro Canyon sandstone (that is, the LaSal mine and ore bodies to the west and north; the westernmost part of Mill No. 1 mine) consist mostly of blue-black ores with corvusite, a little montroseite, rauvite, and black uranium minerals, and probably some vanadiferous clays—all typical of the second or partly oxidized zone.

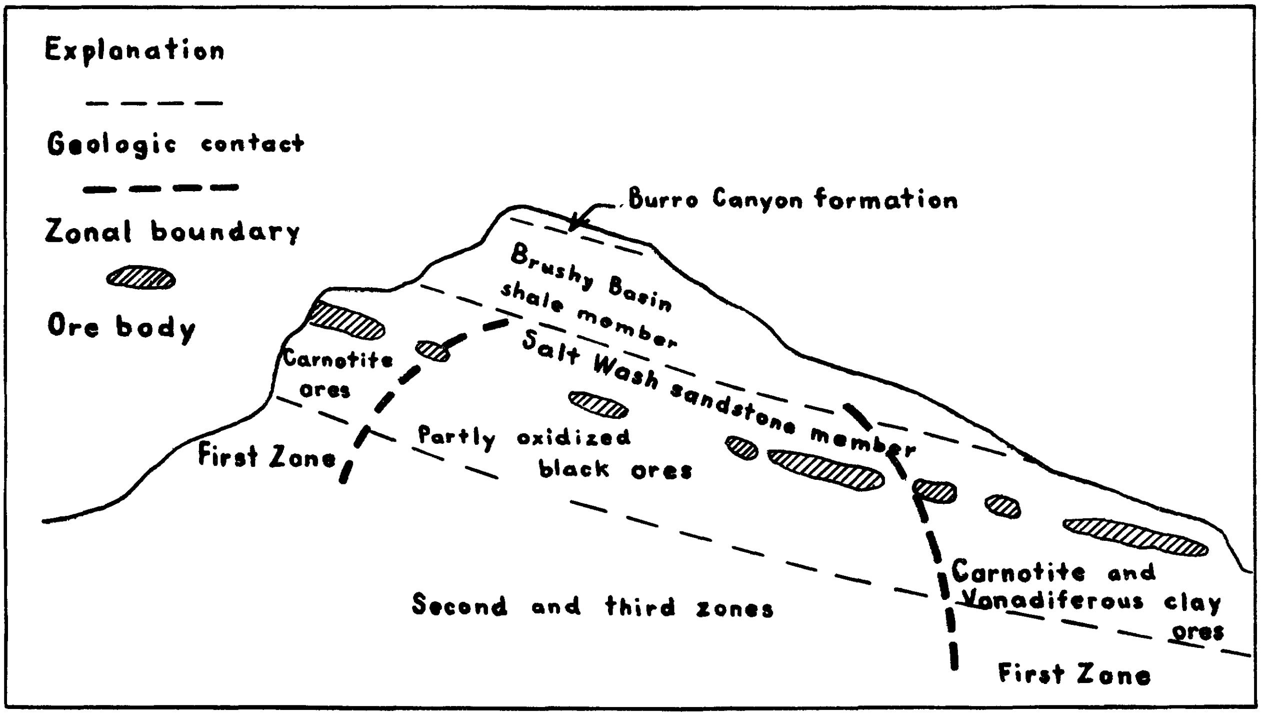

Figure 4. -- Diagrammatic section~~s~~ eastward through Club Mesa, Uravan, Colo., showing relations of zones to ore bodies and thickness of cover

ORIGIN OF THE ZONES

More detailed studies of the geology at Bitter Creek and other ore deposits in the "Uravan mineral belt" are needed before more than suggestions can be made as to the origin of the depth zones.

The depth zones may be evidence of progressive oxidation of primary concretionary vanadium-uranium oxide deposits that contained iron and copper sulfides to secondary vanadiferous clays and carnotite. These oxide deposits may still exist in many places beneath areas that are protected by thick rock cover and in which the deposits are below the water tables but are oxidized through several progressive stages to vanadiferous clay ores where the deposits are nearer the surface and also above the water table (Weeks, Cisney, and Sherwood, 1953, p. 5, 7, 14; Weeks and Thompson, 1953, p. 11-12). Oxidation from sulfides to oxides most certainly occurs in the pyrite and chalcopyrite associated with the vanadium and uranium ores.

Concretionary black ore with completely unoxidized sulfides is restricted to small blocks of gray and white sandstone in the moist, deepest parts of the mine in the third zone. These blocks may represent remnants of a fourth zone, not yet fully exposed, in which no oxidation of the primary ores has taken place.

The rest of the ore in the third zone is in yellow or brown limonite-stained sandstone and probably represents initial stages of oxidation. For example, only some of the pyrite and chalcopyrite has been oxidized, and considerable quantities of these sulfides still remain in the nodules. The irregular knobby nodules of vanadium oxides (fig. 3) may represent

incipient stages of enlargement by diffusion and disintegration of the fourth zone concretions, caused at least, in part by the action of acidic waters formed by the oxidation of the sulfides. A brown limonite diffusion band has formed around the dissolving nodules as the margins of the nodules have moved outward by diffusion, and their centers of leaner ore appear to have formed and enlarged (fig. 2c.). The disseminations and bands of leaner black vanadium oxide ores that surround the partly disintegrated nodules may be reprecipitations of corvusite from acidic vanadium-bearing solutions when they were neutralized by alkaline ground waters as they advanced from the vanadium oxide nodules along more permeable parts of the rock. For example, two nodules are shown in figure 2c near the edge of a sandstone lens between shale layers. The larger nodule is leaner than the smaller ore, is more irregular, has a larger central core of lean ore, is completely surrounded by a diffusion band of limonite, and bands of leaner vanadium oxide ore appear to have advanced in two directions along the shaly layers from this nodule. The larger nodule is believed to represent a more advanced state of diffusion and disintegration than the smaller nodule.

Further diffusion and disintegration of the nodule might have developed it into a roll similar to that shown in figure 2b. The chemistry and mechanics of the formation of such rolls is still uncertain. A simplified explanation is that the rolls represent the advancing diffusion front of acidic vanadium-bearing solutions that are derived from the solution of many nodules and pyritized areas. The curved diffusion fronts might have been formed by reaction between acidic vanadium bearing solutions near the

curved edges of the sandstone lenses and alkaline, oxygen-bearing vadose waters percolating down the more permeable centers of the lenses.

The second zone, which consists of rolls of blue-black vanadium ore (fig. 2b) and only a few nodules, may represent an intermediate oxidation stage in which most of the nodules have been already dissolved and the rolls have developed by a redeposition process such as the one suggested in this report. The iron and copper-iron sulfides have been oxidized and some of the resulting sulfate ions have been deposited as gypsum. The carbonaceous material has been altered, leaving only lignite.

The shallowest zone or zone 1, (fig. 2a) may represent a more complete oxidation stage in which the vanadium and uranium minerals, which oxidize in several stages and more slowly than the sulfides, are further diffused and oxidized to the vanadiferous clays and the yellow "carnotite" minerals.

Several other modes of origin of the zones are possible, such as: (a) the zones represent progressive changes in the original deposition of the ores caused by differences in local conditions, such as increased quantities of carbonaceous fragments; (b) the nodular ores near the present water table may have resulted from a redeposition and secondary enrichment of ores deposited as bands and rolls in the first and second zones, with the first zone being an oxidation product of the second zone; (c) the abundance of carnotite seems to be coincident with the area of the Pennsylvanian evaporite basin (Weeks and Thompson, 1953, p.11) which may be the source of the potassium in the carnotite ores.

Relationships that need further study 5/ in the deposits include:

5/ Suggested by R. P. Fischer, oral communication, November 1952.

(a) a rather abrupt change from the black oxide roll type of the second zone to the nodular and concretionary deposits of the third zone without a marked transition zone; (b) the scarcity of discernible "ghosts" of dissolved nodules in the upper parts of the mine; (c) the elliptical nodules in the gray and white sandstone need further study to determine if they are primary ores or just another transition stage developed from a still earlier form of ore deposit; and (d) if the nodular types of ore are primary, studies of the origin of such deposits should be reoriented to explain the formation of vanadium-uranium concretions under the reducing conditions.

CONCLUSIONS

Depth zoning consisting of 3 distinct zones occurs in the Bitter Creek mine. What are believed to be small remnants of a possible fourth zone are exposed in the deepest parts of the mine. The zones are:

1. First zone: Vanadiferous clays, "carnotite" minerals, limonite, and gypsum, in very well-developed rolls, bands, and diffused disseminations. The ore is low-grade and oxidized in brown sandstone.

2. Second zone: Blue-black vanadium ores and possibly uranium oxides, associated with limonite in less regular well-developed rolls, many bands, and less diffuse disseminations. Nodules are few and widely spaced. The ore is richer. A gradational change occurs between this zone and the first zone.

3. Third zone: Irregular nodules and concretions of rich black vanadium-uranium oxide ore, some rich bands, incipient irregular rolls to form a spotty ore body. Pyrite and chalcopyrite are present but are partly oxidized to limonite. Within this zone are small areas of white and gray sandstone, in which none of the sulfides are oxidized, and the black oxides are in ellipsoidal concretions.

The depth zoning may possibly be the result of oxidation from primary black concretionary ores and associated sulfides. The oxidation of the sulfides could have provided acidic solutions to dissolve the black oxide ores and to redeposit them in rolls by neutralization with descending vadose alkaline waters. Further oxidation or leaching might have produced the vanadiferous clays and the "carnotite" stains.

Depth zoning of this type is not restricted to the Bitter Creek mine but may be common throughout the "Uravan mineral belt". The newer mining has exposed many other examples of black ores beneath the thicker parts of the mesa cap. As mining increases in the areas of thicker cover, a much larger proportion of the production will probably be black oxide ores rather than vanadiferous clays and carnotite ores.

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